Fuel Burn and Emission Forecasting for Europe

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ABSTRACT

Aircraft emissions have received considerable attention in recent years, both on national and international agendas. This has stemmed from the growing awareness of global warming and the fact that aircraft emissions are injected directly into the atmosphere at altitude.

EUROCONTROL Experimental Centre (EEC) first started environmental projects in modelling fuel burn and emissions in Europe by using existing models. New models have been developed and large amounts of data have been collected since, to improve the estimations produced by these models.

EUROCONTROL's approach also aims at reducing a gap that seems to exist between two research communities working in the field: aviation and atmospheric research.

Where the first group is able to provide sophisticated models and data on aircraft operations and movements, the second has an in-depth understanding of chemical processes in the atmosphere.

The EUROCONTROL Environmental Studies Business area aims to work in close co-operation with leading entities in the domain of atmospheric research to establish a win-win situation for both research communities.

This paper presents the results of the first EUROCONTROL studies focusing on the environmental aspect of emissions from aviation.

Three main aspects differentiate the approach presented in this paper from earlier studies:

- Use of real aircraft trajectories
- Consideration and implementation of future improved engine technology
- Gate-To-Gate modelisation
- Significance of the ATM aspect

In order to better understand the implications of existing and recommended international protocols (e.g. Kyoto), the emission study results have an ATM efficiency indication as well.

Potential CNS/ATM benefits are included in the results. The estimation of these benefits is based on the findings of a EUROCONTROL/Federal Aviation Administration (FAA) cooperation study and some other preliminary studies.

Current studies show that there is a potential for flight efficiency due to Air Traffic Management (CNS/ATM) enhancements. We believe that around 5-7% potential efficiency can be achieved by implementing new technologies and air traffic management improvements.

INTRODUCTION

Civil aviation is a growing industry and its development continues on a high level.

Air traffic has continued growing while capacity and environmental constraints have started to limit this growth.

Therefore, understanding of the impact of aircraft emissions on the global atmosphere has become increasingly important.

Such understanding allows focussing on the most important aspects to further improve aircraft and engine technology and at the same time to develop ATM strategies which ensure that aviation grows in a sustainable way.

Several international groups and organisations coordinate and regulate aviation environmental policy to control aircraft pollution.

The adoption of the Kyoto Protocol to the UN Framework Convention on Climate Change (UNFCC) in December 1997 has given increased momentum to the global environmental debate. This has been reinforced by the publication in May 1999 of a special report on Aviation and the Global Atmosphere issued by the Intergovernmental Panel on Climate Change (IPCC) at the request of the International Civil Aviation Organisation (ICAO).

ICAO must meet its obligations, in terms of adopting new technical and operational standards and procedures, improving fuel consumption through improved air routes (notably through worldwide implementation of CNS/ATM), and as regards environmental taxes and charges.

The number, type, performance, and mix of aircraft using the same airspace has changed considerably while the airspace itself hasn't changed significantly. This has resulted in delays, increased fuel burn, higher controller workload, and en route congestion. Therefore aviation seeks for efficiency, which means reduced delays, lower costs and better service.

At the same time, the aviation industry is constantly seeking to reduce its environmental impact to meet the future requirements of national and international regulatory organisations. [1]

Efforts to control or reduce the environmental impact of air traffic have identified a range of options that might reduce the impact of aviation emissions. In particular, it is expected that improvements in air traffic management (ATM) and other enhanced operational procedures for air traffic systems could help reduce aviation fuel burn consumption, and thereby reduce the levels of aviation emissions.

Environmental Studies is one of the Eurocontrol Experimental Centre's (EEC) seven Business Areas and has a growing importance. Since 1998, the EEC has been involved in environmental studies to respond to stakeholder concern in this area.

The main work carried out in the field of emissions is in support of ICAO Council's Committee on Aviation Environmental Protection (CAEP) WG 4 (Emissions and Global Fuel Burn), and recently new studies were conducted to analyse the environmental impact of ATM in aviation.

The EUROCONTROL Global Emissions study estimates and predicts future aircraft fuel burn and emissions for all phases of flight. Additionally, work carried out by the U.S. Federal Aviation Administration (FAA) and EUROCONTROL gives an estimation of CNS/ATM improvements.

In most cases Emission studies have only focussed only on the Landing and Take-off cycle (LTO) with, at the same time, simplified modelling of aircraft profiles.

This emissions study covers Gate-to-Gate operations and most of the aircraft appearing in the traffic samples can be modelled in great detail.

With the "Fleet Change and Technological Improvement Method", developed by EUROCONTROL, a reasonable estimate is

[1] Aviation and the Environment. ATAG. Air Transport Action Group.

obtained for the proportion of future fleet changes and increased efficiency due to progress in engine technology.

In addition, increased route efficiency is considered, based on the results of some recent studies.

EMISSION STUDIES

Global Emission Study

The Global emissions study seeks to forecast fuel burn and emission volumes for a total of twelve traffic scenarios covering a period of 16 years between 1999 and 2015.

Models and Tools Used in the Study

The Aircraft MOdelling Capacity (AMOC) is an Air Traffic Flow Management (ATFM) simulator. AMOC is used to calculate 4D flight profiles for baseline and future traffic samples (using EUROCONTROL STATFOR[2] traffic growth rates for future samples).

The Base of Aircraft Data (BADA) provides a set of ASCII files mainly containing performance and operating procedure data for 151 different aircraft types. In addition fuel burn data is provided. Last data builds the base for the fuel burn estimations for those part of the flight profiles which are above 3000 ft.

The Advanced Emission Model (AEM) is a stand-alone flight data analysis capability and is used in the final step of the fuel-burn and emission calculation. AEM calculates fuel burn and emissions differently for a number of phases of the flight. The version of AEM used here considered five phases for each flight. (See Figure1)

With the new PC version of AMOC, traffic is simulated on a flight-by-flight basis for the chosen days.

Future traffic forecast is predicted using growth rates on a city pair base from the EUROCONTROL STATFOR model.

AMOC 4D traffic profiles are converted to the required format and used in AEM to calculate emissions.

For fuel burn calculations, the Advanced Emission Model (AEM) uses the ICAO fuel burn rates and emission coefficients[3] for flight phases below 3,000 feet.

For parts of the profile which are above 3000ft BADA fuel flow data and Boeing Method 2 (BM2) indices are used.

The BM2 emission indices have been extracted from "Scheduled Civil Aircraft Emission

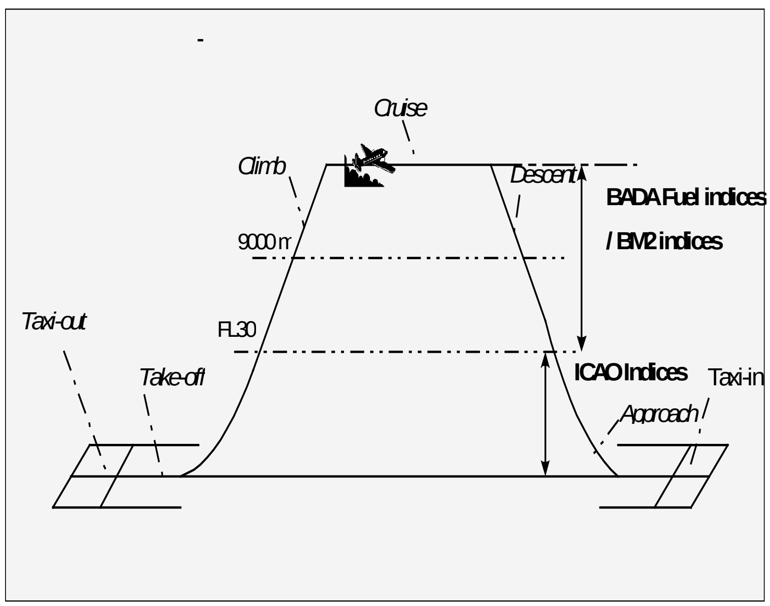

Figure 1. AEM calculation cycle (for the AEM version for this study)

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[2] STATistical FORecasts

[3] ICAO Engine Exhaust Emissions Data Bank", (Doc 96476-AN/943)

Inventories for 1992[4].

The different stages of the fuel burn and emission calculation are shown in Figure 1.

In a newer version of AEM the emissions above 3000ft are estimated applying the Boeing2 method via an algorithmic approach, which is able to estimate more correctly emission indices for cruise altitudes by extrapolation of ICAO LTO engine certification data and consideration of atmospheric conditions at those altitudes.

The Advanced Emission Model (AEM) uses individual flight profile information to calculate fuel burn and emissions produced during the different flight phases.

A large set of operational taxi time data from several airlines is used. This data set is completed for airports where such data are not available by CFMU average airport taxi times. For airports not covered by either of these data sets, ICAO LTO engine certification time for idle operation is used as a default value for taxi operation.

The EUROCONTROL fleet change and technology improvement methods are used to calculate fleet modernisation and technological improvement in fuel efficiency.

EUROCONTROL Fleet Change and Technology Improvement Method

In the context of other projects with a different focus, the approach of increasing the number of movements for future years based on traffic forecasts has proven sufficient. For environmental studies, such a simple extrapolation is not sufficient. The nature of demand for airborne transport will also change. Within Europe we may expect more, shorter flights between smaller cities. Jet aircraft may well replace turboprop aircraft, fast trains may replace aircraft on some routes, etc. One important additional aspect of future traffic is the appearance of new, more efficient aircraft and engine types, due to both fleet modernisation (replacement of older aircraft) and fleet expansion. The fleet change method determines the proportion of the future fleet that will be new compared with the existing (baseline) aircraft. (See.Figure2).

Once the future fleet change proportion is determined, applying the "EUROCONTROL Technological Improvement Method" allows an estimation of technological improvements, which leads to increased fuel and emission efficiency. This method considers recent studies of aircraft/engine type combination and their anticipated efficiency trend.

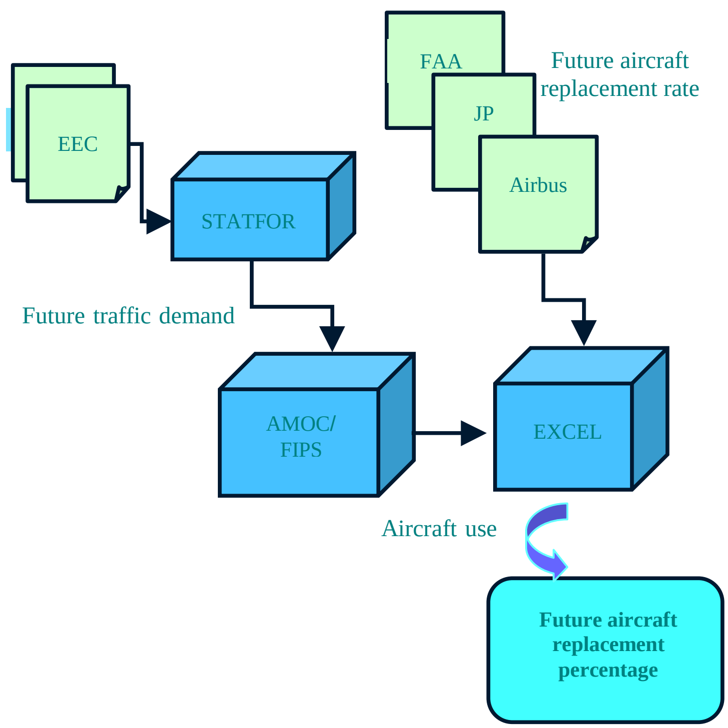

Figure 2. Future Fleet Replacement

[4] Database Development and Analysis, Appendix M (NASA Contractor Report 4700)

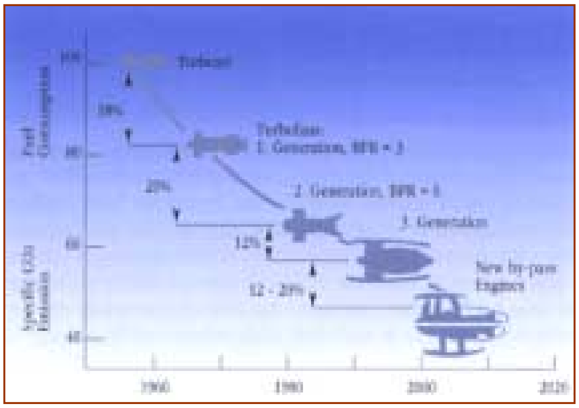

Figure 3. Technology Improvement Curve [1]

From historical engine efficiency data an exponential equation has been derived and is used to produce a trend for future fuel burn and emission calculations.

ATM Considerations

Airspace optimisation is one of the important elements of the strategy to increase the efficiency of European ATM systems. One of the components of the strategy is to include the operational objective of optimisation of the ATS route network and airspace structure. For future forecasts it is believed that there will be a significant effect on flight efficiency and the percentage of traffic delayed by ATM will be much less than today. There are several different elements of a future ATM system, which will have a positive environmental effect:

- Route network optimisation
- Free routes
- Structured routes in TMAs (RNAV)
- Enhancements to Flexible Use of Airspace Concept
- Enhanced Re-Routing Facilities

Free-route and unconstrained "direct gate-to-gate" scenarios especially have a potential for fuel and emission savings.

Limited Airport capacities risk becoming a major constraint for continuous growth of air transport and being one of the causes of delays.

The existing route network system consists of fixed routes with an increasing concentration of traffic on certain routes and flight levels. This concentration leads to congestion and delays. Although ATM related problems are estimated to cause up to 10% reduced efficiency for en-route traffic and in TMAs, the implementation of new ATM concepts and technologies in Europe is not simple. Every European state has its own considerations about technological limitations, security, politics, sovereignty, military areas, and environmental concerns. The traffic situation is highly complex and average flight distances are shorter than in other areas.

For these reasons, it is estimated that the implementation of more direct routings will be limited to only some part of the European airspace.

In Europe, 24 states are applying the flexible use of airspace (FUA) concept. This concept requires considering the European airspace as a continuum, flexible airspace in which, civil and military users co-operate. New technologies in ATM may solve some problems related to the allocation of restricted airspaces.

Environmental efficiency appears to be one aspect of the ATM decision-making procedure. New projects and studies started to measure environmental efficiency and to implement more environmentally friendly solutions.

Free Routes Concept

At Eurocontrol the Free Route Airspace concept is being investigated and several real-time and fast-time simulations have been performed. The primary objective of these simulations is to assess the ATC effect of the Free Route concept.. Besides these effects, we believe that Free Routes have an effect on environmental efficiency. There are possibilities for improving emissions and fuel burn consumption by implementing this concept. Therefore real-time and fast-time simulation results are used for further environmental analysis. The simulations are based on "Eight States Free Route Airspace

Project"[5] which cover the upper airspace of parts of Brussels, Rhein, and Munich FIR/UIRs. The EUROCONTROL Reorganised ATC Mathematical Simulator (RAMS) is used to produce 4D flight profiles, which are used in AEM for emissions and fuel burn calculations.

SUMMARY and RESULTS

Global Emissions Project:

The amounts of fuel burn and CO_2, H_2O and SO_2 emissions found for baseline and future years within the ECAC airspace are shown in Figure 4.

Table1: Average number of flights

	1999	*2005*	*2010*	*2015*
Daily Flights	22,175	29,271	35,083	40,707

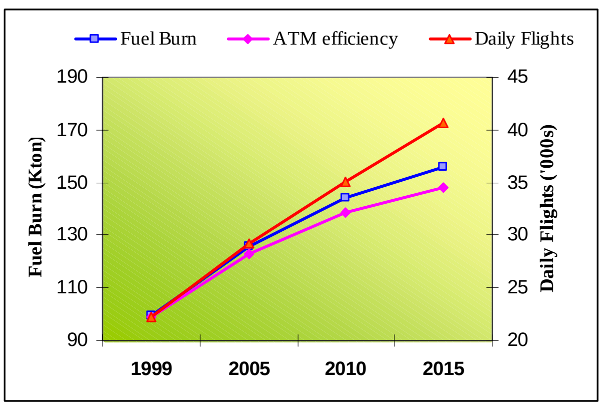

Figure4. Predicted Daily Flights and Fuel Burn for ECAC

The results of the global emission project indicate an increase of fuel burn and directly related emissions of 57% where traffic is estimated to increase by 84%.

The less-than-proportional increase in fuel burn and CO_2 emissions compared with the increased traffic volume is explained by future aircraft replacements and the arrival of more efficient engine technology.

About 55% of the flights appearing in the traffic samples for 2015 use newer aircraft replacing the older aircraft (more than 26 years old) appearing in the traffic samples for before 2015. These aircraft benefit from a fuel and emission efficiency increase due to the progress of aircraft technology.

As is observed in these results, future composition of the aircraft fleet and the accuracy of engine type models can strongly affect predictions. In this study, the global potential for ATM efficiency improvements is considered to be in range of 5% for future predictions. This prediction is a result of the joint FAA-EUROCONTROL study estimating the effects of the implementation of the ATM2000+ strategy elements planned until 2015.

Simulations Results

Early studies show that the use of Free Routes above FL 310 will result in fuel savings of about 3%, while the Gate-to-Gate Strategy could further increase this figure. The implementation of the RVSM concept contributes to around 1% additional savings.

Recently some new studies have been started for Free Routes, and preliminary results confirm a potential of a 2-3% efficiency improvement for the Free Route Airspace.

Where a Free Route concept can not be implemented, modifications of the Fixed Route System can lead to environmental benefits.

A first analysis of the implementation of the new Aeronautical Route Network - Version3 (ARN-V3) indicates this clearly, although major parts of the effects observed are related to the Kosovo crisis in 1999 before implementation of ARN-V3. Further ongoing analysis is currently trying to eliminate this impact and to work out the net effect of ARN-V3 implementation.

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[5] EEC Report No: 365

[6] http://www.eurocontrol.be

FUTURE WORK

EUROCONTROL has started to investigate some simulation results and data, to assess the impact of CNS/ATM concepts (such as Free Routes). Although the preliminary study of Free Routes gives 2-3% fuel savings, more detailed data will be analysed for validation and verification. The simulation results will allow the development of different scenarios and an assessment of the benefits.

While sustainable development is being promoted for environmental issues, just quantifying the fuel burn and emissions is not sufficient to interpret achievable efficiency. Aviation stakeholders can face problems in transferring this information to a business strategy. For this reason, further environmental key indicators have to be developed. The Environmental Key Performance Indicators (ENV-KPI) study, currently under way, is analysing Air Traffic Flow Management (ATFM) efficiency. These indicators will be developed in an evolutionary way over time. Improvements will be delivered based on better data sources becoming available, as well as on refinements to the methods used to calculate the indicators. With this method it will be possible to analyse the operational opportunities for reducing fuel burn as shorter/more direct routes, optimum speed and altitude etc, by comparing live radar data with optimal great circle routes. Preliminary results show benefits in fuel burn and emissions. For more accurate and consolidated results, the data coverage and emission tool will be improved.

From the recent studies it is seen that the main fuel-burn saving in the CNS/ATM system is due to more direct routings, and use of more efficient flight profiles.[7] The emission model (AEM) is still in its development stage, and new features are being added. Detailed data on flight operations, movements and emission output will be provided to the atmospheric research community.

[7] Operational Opportunities to Minimise Fuel Use&Reduce Emissions. ICAOCircular.Draft01a

CONCLUSION

Today, one of the biggest threats to the environment is that of global warming. Changes in atmospheric levels of carbon dioxide are key factors in understanding possible climate change. The absolute CO_2 contribution from aviation is small when compared with total man-made CO_2 emissions (2-3%), but it is directly brought into the atmosphere at very sensitive levels.

In the near future, the Kyoto Protocol will play an important role for the civil aviation sector due to agreements by all nations around the world to limit emissions from aircraft.

All aviation stakeholders have long been looking for efficiency in the industry, trying to reduce costs. This effort has led, at the same time, to impressive improvements in engine technology, which in turn have led to reduced fuel burn and lower emissions. Increasing demand for air transport is absorbing this positive evolution based on engine technology completely. Therefore it is important that CNS/ATM concepts contribute further towards the environmental optimisation of the aviation system.

CO_2, SO_2 and H_2O are direct products of fuel combustion. Consequently, all improvements to fuel-burn efficiency will directly reduce these and other emissions. Thus, it will have a positive effect on global warming as well. The trend towards greater efficiency through aircraft technology and CNS/ATM improvements needs to be maintained and encouraged due to the sensitivity to direct aircraft emissions in certain levels of the atmosphere.

ATM elements, such as improved traffic flow management, route network optimisation, flexible use of airspace, RVSM and Free Routes, which clearly contribute to improve economical and environmental efficiency in aviation, should consequently be integrated into current aviation systems to actively contribute to the environmental goals defined by the international community.

BIOGRAPHY

Ayce Celikel is an environmental specialist working in the Eurocontrol Environmental Studies Business Area as a member of ISA-SOFTWARE. She has been involved in the development of emissions studies and models for aviation.

Frank Jelinek is an aviation engineer working for EUROCONTROL with in- depth practical experience in the domains of aircraft performance, ATC/ATM modelling and Fast-Time Simulations. Before joining EUROCONTROL in 1994 he worked in the aviation and airport related software industry (Lufthansa (LIS) & ABB (former CCS)).

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